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Bulletin No. 123 - Farm Drainage: A Manual of Instruction

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Utah Agricultural College
EXPERIMENT STATION

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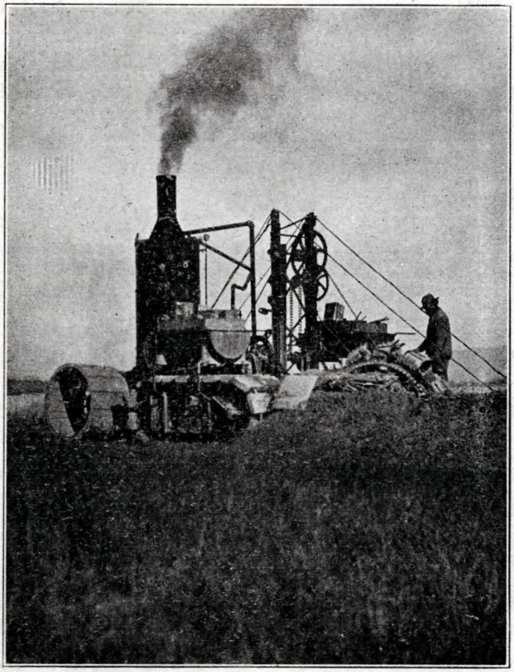

FARM DRAINAGE
A MANUAL OF INSTRUCTION

By
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CHAS. F. BROWN

INTRODUCTION.

In addition to emphasizing the general need for drainage in the arid regions with reference to seepage and alkali problems, this bulletin is intended as a practical treatise covering all engineering phases of farm drainage, from the general observations concerning specific needs of drainage, to the realizations of successful reclamation. It is made up of two parts for convenience in handling and distribution, Part I, Manual of General Instructions, and Part II, Practical Discussion of Problems.

The bulletin is a logical outcome of a series of co-operative investigations and practical field demonstrations in this State between the Utah Experiment Station and the Drainage Investigations of the Office of Experiment Stations, U. S. Department of Agriculture. Most of the work was carried on between the years 1905 and 1910, inclusive. In addition to these investigations, which were under the direct supervision of the writer, he was also in active charge of similar work in the states of Wyoming, Colorado and Texas, U. S. Drainage Investigations, and since 1909 has been engaged in drainage engineering practice throughout the West.

Very few who are familiar with the agriculture of the irrigated regions have failed to recognize the presence of the seepage and alkali problems and the serious handicap thereby placed upon portions of most irrigated regions. From small portions up to 50 per cent of some tracts are thus rendered unproductive and have been abandoned. As early as 1857 letters were addressed to the Pioneers of Utah from India, concerning the successes the former were purported to have in ridding the arid plains of their excess of alkalies, and yet after 30 years we are just beginning to correct our mistakes. There is a striking agreement between the remedies proposed by the Indian engineers and chemists at that time and the best practices today. The question is one that confronts every irrigated section, and will always require attention, and the only final and universal remedy is underdrainage. No movement would be more conductive to soil conservation in the arid regions than an awakening to the possibilities of underdrainage.

The possibilities of reclamation of these once productive, but now abandoned fields, through underdrainage are just beginning to be realized. The successful realization is not dependent on the capitalist as are the remaining irrigation projects, but upon the individual farmers owning the lands. They are near the cities, on the railroads, and under the irrigation canals, and range in size from a few acres to several thousand, and will offer an excellent field to small investors.

Recognizing the Need of Drainage.

The native vegetation is very closely connected with the character of the soils and their different constituents. Experience has demonstrated that the natural growth furnishes a key to the agricultural value of virgin lands within quite wide limits. There are certain trees styled lime loving, indicating an abundance of that element of soil fertility; others lime repellent, indicating the reverse. In the development of the Western arid regions, certain bushes, such as sage and rabbit brush, have come to be taken as almost sure indications of the good quality of the lands supporting them. On the other hand, certain other natural flora, such as salt weeds, grease wood, salt grass and shad scale, are recognized as indications of the presence of alkali in varying quantities. These different types of vegetation also indicate relatively high percentages of alkali, beginning with the sea blite (Sueda) the jointed fleshy salt weeds common to the old lake bottoms, which indicate the largest amount of common salt and total alkali, down to shad scale, which sometimes grows on lands containing less than .2 per cent. In the native or virgin state lands covered with vigorous growths of the first three alkaline types of vegetation are not capable of reclamation except by underdrainage and subsequent leaching. Not all lands capable of being reclaimed are worth the cost required, but as land values rise the acreage susceptible of profitable reclamation will increase.

The irrigation and cultivation of lands growing the other alkaline types is nearly always followed by accumulations of alkalies upon the lower lands by seepage from the higher areas. The reclamation of such lands when natural underdrainage is insufficient, as on the low valley lands, is practically impossible without artificial underdrainage. They usually grow fair crops for a year or two, until the first three or four feet of soil is filled with water, after which they become unproductive and revert to salt weeds, etc. Such lands should be provided with underdrainage before attempts at cultivation so that the excess of water could flow away, removing the natural excess of alkali of the lower portions. With such treatment these lands would continue to grow crops and become more productive for many years, as their wonderful fertility has been demonstrated.

It usually takes one or two seasons after failure to effect the transformation from cultivated agricultural crops to the native alkaline vegetation; but it always follows seepage accumulation of alkali, and is just as sure an index of the character of the soil ingredients as on virgin soil.

Another significant indication of the need of drainage sometimes noted is the remarkable change from just ordinary crops to very luxuriant growth the season before failure. This may possibly be due to more favorable moisture conditions at a certain season. This is quite general and very noticeable, especially with sugar beet culture.

The growth of certain plants, such as fox tail, tules and joint rushes, is a sure indication of an excess of water. Cultivated crops will also show an excess of water by the change in color of their foliage. Cereals and most farm crops and fruits become yellow very quickly following an excess of water, indicating the need of drainage when such is not caused by too much irrigation. The chief danger arising from an excess of water is the consequent alkaline accumulation so common, very few localities in the arid regions admitting of the supply of soil moisture by seepage.

Another means of determining when to drain is furnished by the action of seeds and growing crops. The failure of seeds to germinate, or early death of plants when not accountable for by other reasons may be due to the presence of too much alkali. The burning of field crops and of leaves on trees has been known under such conditions.

Surface discolorations of the soil are also sure signs of too much alkali, and are nearly always noticeable before failure. To the practical observer they furnish evidences of the relative extent of injury, and are nearly always present on cultivated land after failure.

The common alkalies are composed of varying proportions of sodium carbonate (Black alkali), sodium sulphate (Glauber's salt), magnesium sulphate (Epsom salt), sodium chlorid (common salt), calcium chlorid and some others. They are always found in combination, but where one is dominant, one-tenth of one per cent by weight of the dry soil for black alkali, one-fourth of one per cent for common salt and from one-half to one per cent of Glauber's salt are the limits allowable for thrifty growth, the tolerance varying for different plants and different soils.

The name "black alkali" arises from the black discolorations on the surface, and is due to the solvent action of sodium carbonate upon the humus of the soil. Pure sodium carbonate is white and has the same general appearance as the other alkalies. Calcium chlorid draws moisture both from the ground and atmosphere and is sometimes mistaken for black alkali. Sodium chlorid, or common salt, is also accompanied by some darkening of the soil surfaces. Black alkali also has a tendency to puddle clay soils, making their reclamation very difficult even by drainage.

With a little care and effort it is possible to classify the different alkalies in the field. Common salt and Epsom salt are readily recognized by the taste, and black alkali solutions will turn red litmus paper blue within a minute. Crystals left on the tongue for a short time are very biting. Glauber's salt is cooling when placed on the tongue and not unpleasant. For large areas, soil and water samples should be taken and chemical analyses made of the same before planning reclamation. Unscrupulous real estate agents and others engaged in selling lands have in a number of instances stated that the well known efflorescences common on alkali lands were "white moss" and gypsum, both harmless. The writer has never known of such discolorations being due entirely to gypsum, and there is a question as to its harmfulness.

Excess of water is universally recognized as a condition in which drainage is needed, and in the irrigated regions it is usually due to rise of ground water through irrigation. It sometimes occurs in the early spring, preventing proper preparation of soil and early cropping, or during the irrigation season soft spots may occur and remain continually wet, preventing cultivation and harvesting. Instances have also been known where the rise of seepage water came late in the season, preventing harvesting. The time of "subbing," as it is sometimes called, from local irrigation is dependent upon the character of the sub-soil intervening and the distance from the source and time of irrigation, so that no general rule exists as to time of rise of ground water. The fact that some lands have relatively steep surface slopes is no assurance against seepage, large areas sloping from 25 to 100 feet per mile having been ruined by seepage. Mesas high above general valley elevations have also been troubled with seepage and alkali. Surface slope is often confounded with natural underdrainage by the novice, and ground water has been known to rise 40 or 50 feet within 15 to 20 years, so that predictions regarding seepage are extremely difficult.

Sub-Soil Examinations.

Sub-soil examinations by means of soil augers, test pits and probes are highly essential to the intelligent understanding of local conditions and profitable reclamation. One of the chief needs of such operations is that of determining or confirming evidences of the need of drainage. A thorough knowledge of underground conditions, at least to the depth of drainage, is absolutely essential, and failure to make such examinations has resulted in losses which could hardly be afforded. The soil auger used freely may indicate an approaching rise of ground water and suggest precautions that might save several crops and final abandonment. Test pits and samples of water therefrom would indicate the character of the seepage water, as to whether it was heavily laden with alkali or not. The soil auger is also used very frequently for taking soil samples from different depths for making qualative and quantitative analyses for alkali and plant food. Injurious quantities of these salts may be detected by simple field tests already enumerated, with some modifications. One method is that of leaching small quantities of soil and then removing the water by

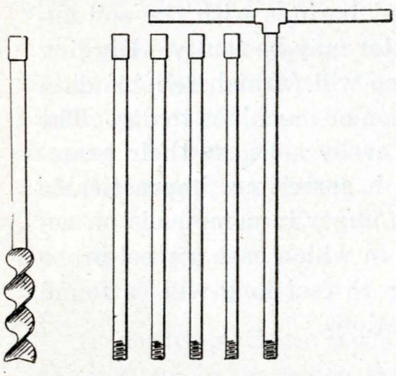
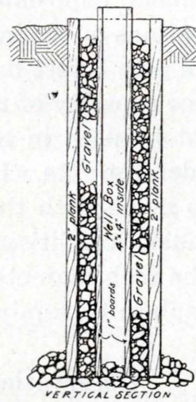


FIG. 1
SOIL AUGER



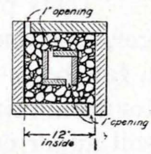


FIG. 2
GROUND WATER
OBSERVATION WELL

evaporation from the solution in a silver spoon and examining the residue. The writer has detected the presence of alkali in dry soil by tasting.

It is possible sometimes to locate the special sources of ground water by means of the auger, thus assisting in the location of drains. On some of the experimental work mentioned in the introduction it became necessary to lay the tile just on top of a stratum of sand. This would have been practically impossible in caving soils, without first determining its postiion by boring, and then making the grade to conform. Its use may uncover some porous substratum wholly unthought of, with its resultant effect upon making efficient plans. This simple tool, which can be made by any blacksmith and shown in Fig. 1, is indispensable to every farmer engaged in reclaiming seeped land and in keeping his irrigated farm up to a high standard of efficiency. The free use of this tool is essential to making reliable cost estimates for trenching, etc. A few thousand feet of hardpan in a field being reclaimed, if unknown, could easily make the difference between success and failure. Too frequently is work of this kind undertaken with limited capital and no knowledge of the difficulties to be met.

Tests pits should supplement borings with the soil auger, as interpretations of the latter may be faulty. Digging a few holes from 4 to 6 feet deep will furnish reliable data for estimating the capacity of men or machines to dig. The soil auger cannot be used in gravelly soils, so their examination is dependent on pits. It is sometimes impracticable to dig pits or do much with the auger in some soils on account of their mushy condition, in which case a steel probe about five-eighths inch diameter 15 feet long will be found convenient for sub-soil examinations.

Observation Wells.

Observation wells afford the best means of making long time observations for determining the fluctuations of the ground water table and the quality of the soil water. Weekly measurements of depth should be made, and samples for analysis as circumstances require, possibly two or three times a year. Wells for this purpose were put in on several of the experimental tracts, but they had a tendency to seal up, being open only on the bottom. Wells constructed as shown in Fig. 2 will prevent this. In some regions the ground water rises to near the surface during some seasons and then recedes to 10 and 15 feet below the surface. In fruit culture it is highly important to know if this is happening. If the ground water table is naturally low in the growing season the tree roots may grow deep in search of water, only to be submerged for a long period later, damaging the trees seriously. In many instances tree roots have extended from 8 to 10 feet below the surface in the earlier years of irrigation, and have subsequently been seriously injured by the general rise of the ground water table to 6 feet, which is considered sufficient for fruit culture. In such cases the only means of saving the trees would be to lower the water table by drainage, which is too often impracticable. For further discussion along these lines see Ground Water, Part II, of this bulletin.

The data collected by taking measurements of the fluctuations of ground water, together with observations of the character of soil is useful in forming an estimate of the amount of drainage water to be removed in a definite time, and the consequent size, depth and spacing of tile lines. These suggestions will be taken up more in detail in Plans for Drainage; the object in mentioning it here being to impress the need and value of observation wells.

In locating these wells considerable care should be exercised so as to secure the most from a given number. It is advisable to place some on the outer edges of the affected area as well as on the interior, and if the tract being observed consists of different soil formations the wells should be located with this in mind. When possible they should be located where they will offer the least interference with farming or construction operations. Plans for such wells are shown in Fig. 2. The outer casing with sand and gravel filling is only necessary in fine sand and silt; the single box being sufficient for clay, gravel or reasonably firm soils. The hole and casing should be deep enough to permit of a wide range of fluctuation, usually from 6 to 10 feet. The spoon-shaped telephone scoop shovel and bar are very convenient tools for digging the holes. From 1 to 3 or 4 for each 40-acre tract, depending upon local conditions, will be necessary.

The value of chemical studies in determining the need of drainage will be apparent and should be made when there is much at stake. The soils of every new irrigation project should be sampled and chemical studies for determining soil constituents made, instances being on record where very expensive irrigation works have been constructed to supply water to worthless alkaline land. In the regions of light rainfall it sometimes happens that the great bulk of injurious alakli is driven to depths of from 1 foot to 3 feet below the surface, allowing shallow rooted plants to thrive, indicating to the inexperienced, comparative freedom from alkali. An inexpensive soil survey would have revealed such a condition. The presence of considerable sodium carbonate at such depths in a clay soil would render the same irreclaimable. Such a survey is often advisable on large tracts to denote or detect any change in alkaline formations when cropping operations are unsatisfactory or injury from seepage is suspected. The cautious business man and scientific farmer of today are demanding such information in cases where actual demonstration by growing crops is not possible. There are certain well known elements necessary to the profitable growing of crops and certain others interfering with and preventing successful cultivation. When the soil productivity has been demonstrated, as in the case of most seeped lands, only analyses for alkali are necessary. Such a survey should not cost to exceed $35 to $50 per one-half section, and the farmer who is careful can take the samples. Several auger holes should be made and the soil from each set thoroughly intermingled before selecting the sample, usually a 1-quart jarfull. It is customary to select samples of the surface foot and also the total six feet. The soil chemist directing the work should be consulted as to the number of samples to be taken and for other specific instructions.

Too much stress cannot be laid upon the importance and value of providing underdrainage in the earliest possible stages of seepage and alkaline accumulations. Experiment has shown that the time taken for the removal of the injurious salts and the restoration of the soil to its natural conditions is in direct proportion to the time it has lain uncultivated after failure. The Garland Experiment, referred to in Bulletin 371, was drained immediately after the first crop failure, with a return of production the following season, 1911, a crop of 20 tons of sugar beets per acre being harvested. Other similar lands drained after 8 to 15 years of failure and abandonment, have taken from two to four years to reach normal production. One of the chief difficulties attendant upon reclamation of water-logged and alkaline lands is that of restoring the mechanical condition of the soil to its former condition. If taken early the condition of the soil is practically unchanged.

Plans for Drainage.

Reliable cost estimates and the decision to undertake reclamation can hardly be arrived at properly until the plans necessary are formulated, and the approximate quantities of material required and labor to be performed are determined.

As a basis for making these estimates all but small areas and simple systems require more or less surveying. The difference in elevation between points within the area to be drained, and the outlets available are essential in fixing grades and determining the size of tile or ditches necessary. Practically all tile lines should be marked by stakes showing the cuts to grade and placed every 100 feet as guides in digging. Trenching machines need checking by grade stakes every 100 feet. In addition, all such work should be located with reference to property lines and corners and properly platted and mapped to scale. The engineers transit with bubble attachment is sufficiently accurate for the leveling and is convenient in locating natural objects, drains and boundaries by means of stadia measurements. For larger areas, over 1000 acres, the plane table survey for topography is advisable in open country. The cost of making such surveys will be found in the section entitled Cost Estimates.

If the soil auger test pits and observation wells have not been used in making soil examinations for evidences of the need of drainage, then they must be made in determining the methods to employ. The general plan of laying out parallel lines cannot be followed in the drainage of irrigated lands, as it often is in the humid regions. Centuries of copious precipitation in the latter has caused the formation of innumerable small pore holes and natural drainage channels from the surface to the underground waterways and thence into surface channels. Just the reverse is true in the arid regions, the only channels formed in these soils being those of the water doing the damage, usually the rise of the general water table or the upward pressure of underground reservoirs of seepage water. The soils are generally homogeneous and compact, preventing the natural flow downward. Under such circumstances it becomes imperative to look for the direct source of the supply, and seek to divert the flow from lateral seepage, as along the foot of a bench, (Fig. 3), or to intercept the inflow from special channels, as through coarse shale in the Colorado Plateau. In Emery County, Utah, and portions of western Colorado it is almost impossible to construct drains in the deep silt deposits kept wet by such water until the supply has been intercepted. Such expedients as washing out an open ditch channel by water are often resorted to before such sources can be tapped. It is not always possible to lay outlet drains deep enough to reach the porous stratum or channel, so that wells connecting the drain with such channel or stratum, affording a free outflow and consequent reduction of pressure head, are often constructed. These are called relief walls and are shown by a sketch drawing in Fig. 4. Instances have been noted where tile laid at ordinary depths above such sources have failed to drain the land. The writer detected the presence of water bearing gravel by punching a hole with a crowbar in the bottom of a trench, from which a flow rose an inch above the general level of the water in the trench. Water stood on the surface within a few feet of the tile line. Later an 8-foot ditch, cutting into the gravel, relieved the pressure from an 80-acre farm, effectively draining it.

The other method, though seldom used alone in the irrigated regions, is that of following the natural drainage channels or the low ground. For the reason mentioned

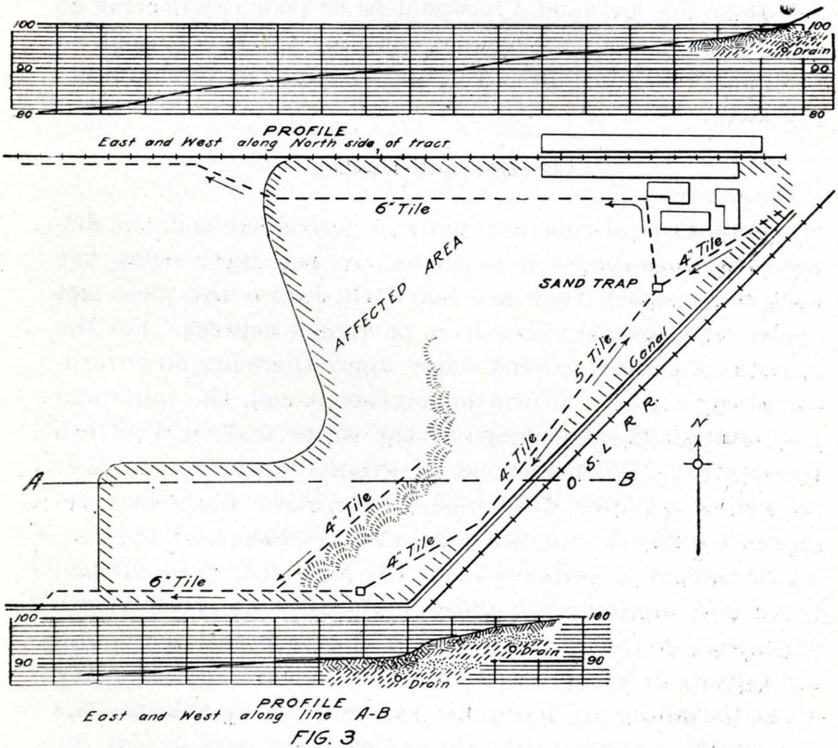


FIG. 3

WASATCH ORCHARD CO'S FIELD

OGDEN UTAH

Showing method of draining by intercepting lateral seepage

above its use alone is not satisfactory. It is necessary in most reclamation schemes for the purpose of furnishing an outlet for intercepted drainage, so that in practice the two methods are combined. In farm drainage it is often advisable to provide drainage in low or flat places to prevent ponding of irrigation water and its injurious results, it being also advisable where relatively large amounts of snow and rainfall in the spring time. Where there is much alkali present, drains should be located in the lower portions to facilitate the downward movement of water when being leached. Large outlet drains for districts are of necessity required in the low places to afford adequate outlet service for adjoining low land. It would be as poor engineering to locate a main drainage canal on any but the lowest land, as it would be to construct an irrigation canal in a general depression.

Location and Depths.

As a general rule, especially in porous sub-soil, the distance between drains is dependent on the depth below the surface at which they are laid. Of course this does not apply to the special inflow from particular sources. For the removal of general ground water where there are no governing strata, but a uniform homogeneous soil, the minimum hydraulic gradient or slope of the water table will govern the depths. The movement of ground water in drainage requires a greater difference in elevation than that required for flow in surface channels. The slope of the free water surface is referred to as the hydraulic gradient and there is a minimum at which practically no water flows, varying from 1 foot vertical in 150 or 300 feet horizontal for gravel, to 1 foot in 24 for compact clays. Prof. King gives the minimum hydraulic gradient for clay loam soils as 1 in 36, meaning that the water table rises 1 foot for each 36 feet away from the drain. In such soils the water would stand 2 feet above the tile at a distance of 70 feet, so that for a minimum depth of 4 feet for the water table, tile would have to be spaced 140 feet if 6 feet deep. Experience in the irrigated regions has demonstrated the best depth to be between 5 and 6 feet. Very few soils will stand without shoring at the greater depths, so it is seldom advisable to put tile deeper, though in the case of some gravelly soils requiring shoring at ordinary depths it is better to do so. A single line of tile 8 to 9 feet deep on

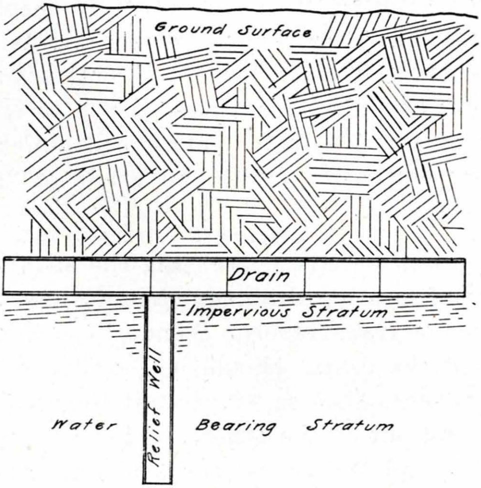


FIG 4

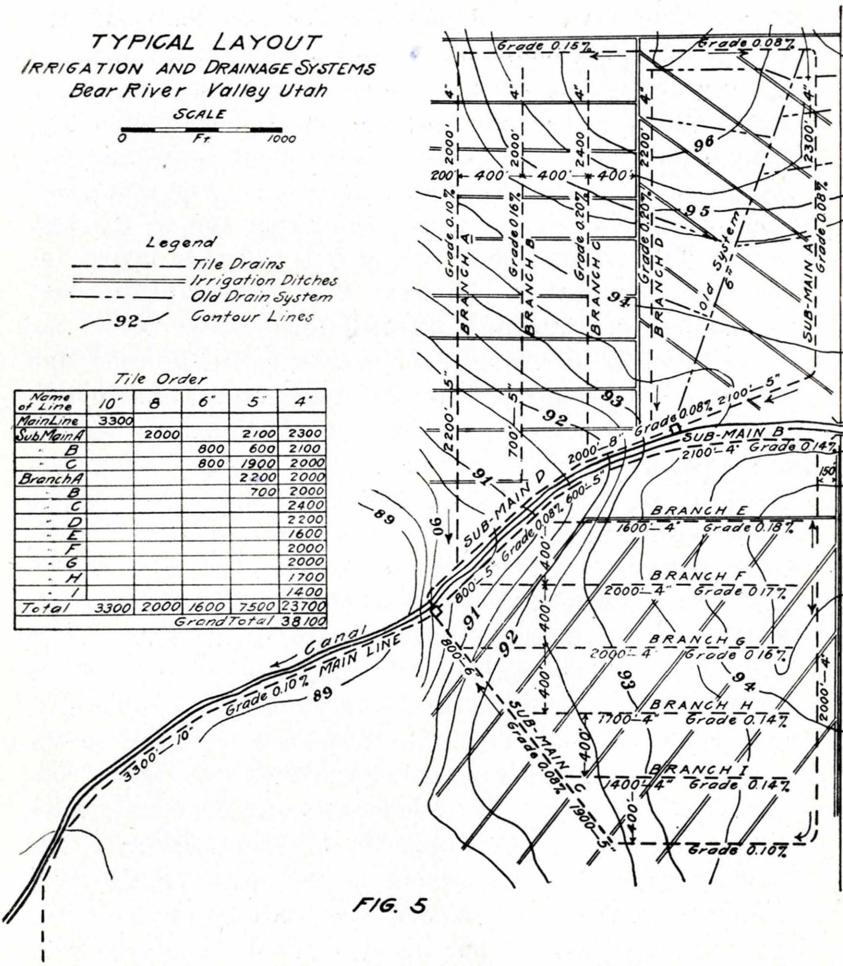
the Willow Glen Stock Farm, Deer Lodge County, Montana, drained a one-half-mile strip in a coarse gravelly sub-soil. In the usual loam soils of the irrigated regions a distance of about 400 feet apart with tile from 5 to 6 feet deep will be found sufficient. Special strata, as water bearing, fine or quick sand or even hardpan may vary these depths.

Another controlling feature to be taken into account in the arid sections is that of the rise of ground water by capillarity when within 4 feet of the surface, together with its heavy evaporation and consequent accumulations of alkali in the surface soil. Depths less than 5 to 6 feet are consequently inadequate. In no case should tile be laid less than 4 feet deep; a box drain $3\frac{1}{2}$ feet deep carrying highly charged alkaline water allowing a heavy deposit on the surface. The dissolvent action of seepage water on the various salts of the soil and the subsequent evaporation, leaving the salts on the surface is the direct cause of alkaline accumulations. Water will rise from depths of about 4 feet in injurious amounts, hence the need of deep drainage.

Open ditch outlets for districts must be deep and wide enough to carry the discharge at sufficient depths below the surface to permit a free outflow for lateral drains. As a rule such ditches should have a clear depth to the surface of the water of about 6 feet. Submerged outlets for tile prevent proper discharge unless the grade of the lateral is great.

Much has been written concerning the advantages and disadvantages of locating drainage channels parallel to the maximum slope or transversely. Some of the older authorities claim that the drains should be parallel to the slope, especially in coarse sub-soils, to prevent the water passing into one side and out of the other. Later, other engineers advised ditches and tile across the slope, contending that the ground water would lie in practically level planes passing through the bottoms of the drains and that these levels would be stepped down by such drainage. Careful ground water observations have shown, however, that the water plane is practically parallel with the surface, so that with comparatively steep slopes it is best to lay the drains with the slope. The ground water table observations referred to above were made on the Experiment Station Farm at Laramie, Wyoming, a system designed and laid out by the writer and reported in Bulletin 90, Wyoming Experiment Station, entitled "Reclamation by Drainage." Practically all successful efforts at drainage in such formations have been laid out approximately parallel to the greatest slope. "Seepage and Drainage," by E. T. Tannatt, Montana Experiment Station, discusses this question in relation to the gravelly soils of the Gallatin Valley, and presents the same general conclusions.

In the location of lines intended to intercept general lateral seepage in irrigated fields it is best to place them in the wet area within 150 to 200 feet of the upper edge, the effect of such drains reaching much farther below than above. Only in large, comparatively smooth fields, affected about the same throughout, is it the practice to lay out lines a uniform distance apart, natural topography, such as slopes, draws and depressions controlling the location to a large extent. Excessive quantities of alkali in patches will require drains at more frequent intervals. For small portions it may be best to place them from 100 to 200 feet apart. The system shown in Fig. 5 is a typical layout for the clay loam soil of the Bear River Valley, Utah, wet throughout, and generally affected with alkali. All of the data, including the contours, or lines of equal elevation, and irrigation ditches are shown. The old system in the northeast corner was inefficient on account of shallowness of drains, being from 2½ to 3 feet deep. This particular system has not yet been installed, but hundreds of acres in the same locality have been successfully drained by about the same methods. A large part of the trouble on this farm has been occasioned by the method of irrigating. Proper methods of distributing irrigation water giving general submergence without ponding are of prime importance in handling lands having a tendency to excessive alkalinity. Only the north half of this farm has been irrigated in the past, the check method being employed with the levees running east and west throughout, and irrigation was always accompanied by ponding and its injurious effects. The flooding method of discharging on the upper slope and allowing a general overflow with light checks on the lower side, but not ponding, has been proposed. To accomplish this the distributing laterals are run at an angle of about 45 degrees with the direction of the maximum slope, the checks being made by the waste from the small ditches, which is thrown mostly on the upper slope. The water is turned out of these ditches at the highest point in the check to begin with by means of a steel plate dam, and when the flooding has reached the opposite side of the checks and covered a convenient area the check is pulled and the operation re-



Tile Order

Name of Line	10"	8	6"	5"	4"
MainLine	3300				
SubMainA		2000		2100	2300
" B			800	600	2100
" C			800	1900	2000
BranchA				2200	2000
" B				700	2000
" C					2400
" D					2200
" E					1600
" F					2000
" G					2000
" H					1700
" I					1400
Total	3300	2000	1600	7500	23700
				GrandTotal	38100

FIG. 5

peated further down the slope. This method is the most efficient in the distribution of water and is used extensively in this valley.

In fixing depths, the available slopes must be taken into account. That is, if a lateral must be constructed 1000 feet long on flat ground, a slope of .1 foot per 100 feet would require an outlet depth of 5.5 feet if the minimum depth at the upper end were to be not less than 4.5 feet. Preliminary surveys and paper locations in the field preparatory to final location are highly important. It is frequently necessary to lay outlet drains less than 4 to 6 feet deep, but they have no value to adjoining land until depths of 4 feet and above are obtained. Deep drainage as compared with the practice in the humid regions is an indispensible requisite to successful removal of alkali.

Kinds of Drains to Employ.

This division consists of two parts, or general classifications: Open Ditches and Covered Drains. Each has its particular advantages and disadvantages, both being in use and probably always will be. Open ditches, by reason of the low first cost for large carrying capacities, are particularly adapted for district outlets. Their construction through soft swampy soils is possible by machinery without shoring the sides, and in most instances such ditches would have to be constructed as usual before tile could be laid. They answer the purpose in the beginning, but as the land values increase and expenditures for maintenance by cleaning become necessary, the tendency is to lay large tile, practically eliminating maintenance charges. This is especially true in the older humid regions. The unit cost of excavation in cleaning is much higher than original excavation, the chief reason for this being the small quantity to be removed and the difficulty of operating dredges, etc., over old lines. So that, for such ditches the cost of cleaning after 8 or 10 years almost equals the first cost. Unless the side slopes of the ditch are very flat, from 1½ to 1, or 2 to 1, there is a tendency to cave in, obstructing the water channel very seriously. Even with these slopes, caving sometimes results from fine sandy and silty spots, this seemingly being more frequent in the irrigated regions than elsewhere. There is one natural advantage in the arid rgions making it possible to have fewer open ditch outlets than would otherwise be necessary, and that is the relatively small discharges of drainage water to be provided for, due to light rainfall and no surface runoff. Another advantage is that of not having to provide for hill drainage with its consequent deposits of sand and gravel, etc. In some clay soils, open ditches will stand up fairly well with slopes of less than 1 to 1, but a uniform soil for any considerable length of ditch is unusual, so that they cave down in places, causing obstructions. One of the chief disadvantages of open ditches in the West is that they form a regular trap for rolling or tumble weeds, so common. When these get in the ditch and a little sand collects about them, it is impossible to remove them except by removing sand and weeds together. In some instances the writer has specified woven wire fences on both sides of large open ditches to intercept the weeds in localities where the Russian thistle and tumble weeds are prevalent. Even then they would have to be gathered and burned at short intervals. But after all is said there is a place for open ditches, though almost exclusively confined to use for large outlets. For farm drainage they are ill adapted, occupying too much land with their great top widths and waste material; they offer the maximum of inconvenience to cultivation, etc., and have every disadvantage enumerated for outlet drains and comparatively none of the advantages. Their carrying capacities are low on account of the great resistances to flow, occasioned by roughness, caves and weeds. The first cost is but little below covered drains of sufficient capacity, and the annual maintenance soon exceeds the cost of tile drainage. They are much more subject to damage by irrigation water than the covered drain is. The writer was instructed at one time, against his wishes to construct open drains for a tract of 240 acres for a company, at a cost of approximately $10.00 per acre. He did so, making them 5 feet deep on an average with side slopes ranging from about ½ to 1, to 1½ to 1. Within 3 years after completion they were three-fourths filled by natural agencies, such as frost, irrigation water, caving, etc. The money was worse than wasted, for it delayed the development of the tract 5 years. He has since had the satisfaction of laying out a complete tile system for this area and noting its successful reclamation.

Covered drains of many forms have been in use from the earliest efforts at drainage. Among the most primative ones are those using stone for sides and top, gravel and brush filling, and mole plow drains. Each one of these has been "invented" in almost every irrigation section and was seriously expected to revolutionize the whole practice. The mole plow "inventor" is the most persistent and the method the most likely of any to fail, though there are numerous examples of the failure of brush and stone drains caused by the washing in of soil and sand by irrigation water. The carrying capacities of such drains are small and the tendency to become obstructed so marked that they are scarcely worth consideration.

The round clay tile has come to be used almost exclusively, though many other forms have had their advocates. This form is most easily manufactured and is best adopted to the different demands made on it, and when well burned it resists all corrosive agencies and conditions to which it is naturally subjected. Its durability in alkaline ground has been questioned, but there are no authentic records of its having failed from that cause. Instances have been reported, but investigation so far has shown other more probable causes. We have seen some soft clay tile removed from highly charged alkaline soil and water near Montrose, Colo., after 18 years of subjection, and not the least bad effect could be detected. Some instances were thought to be frost, as the tile was in a very cold section and only 2 feet deep. The writer has never known of the disintegration of even the soft clay tiles after being properly laid below the frost line. Small sizes, under 8 inches in diameter, are usually made in 1-foot lengths, though some engineers have ordered them made in 2-foot lengths for smoothness of grade in soft ground. As practically all the water is admitted through the joints, even in the most porous clay tile, this may not be the best practice. If the soil will not hold the tile without danger from vertical displacement a board should be laid under them to furnish a foundation. It is doubtful if the increased length of tiles 2 feet long will prevent slipping in soft ground and it is not necessary in firm ground. In some cases smooth tile have been laid so closely together that the ground water could not enter. As a rule, though, this does not occur, but indicates the need of openings.

Cement tile has taken a prominent place in land drainage of late years, and in many localities where clay tile cannot be procured or are prohibitive on account of high freight rates, the former are being used to good advantage. As a large portion of the total aggregate is sand, obtainable anywhere, it is possible to ship Portland Cement to such localities for making tile. For sizes above 8 inches they can compete with clay tile, even when made by hand molds. The usual proportions are: 1 of cement to 3 of sand and fine gravel. Instructions for making them can be obtained from cement manufacturers and dealers and from the molding machinery companies.

One of the chief objections to the use of cement tile in alkaline formations is the danger of disintegration caused by the alkali. Several instances have been reported of late years which have led to much discussion and some experimental work. Among a number of others, Mr. R. A. Hart, U. S. Drainage Engineer, made some laboratory tests, reported in Trans. American Society of Civil Engineers. The consensus of opinion is that the sulphates are the principal agencies of destruction. A concrete sewer at Great Falls, Mont., is about the only very serious failure reported. A considerable amount of cement tile has been used in the irrigated regions under the observation of the writer with satisfactory results. If such tile is made of a 1 to 3 mixture and properly cured we would not hesitate to recommend its use, particularly where there are large quantities of water to remove, as in gravelly soils. The outlet of the Richfield Experimental system, one of the co-operative demonstrations, consists of 500 feet of 10-inch cement tile made of a 1 to 5 mixture. The tile was rather poorly cured, but has stood well since the fall of 1907. At the end of the first year it seemed to be softened some in places, but examination four years later in the fall of 1911 showed it to be in good condition. This tile was laid in lands having a total alkali content of .4 to .6 per cent in the first 5 feet. The total alkali as shown by two samples of crusts collected near Richfield consists of 5.91 and 7.46 per cent of calcium sulphate, 31.00 and 31.00 per cent magnesium sulphate, 23.53 and 13.05 per cent of sodium sulphate, 37.11 per cent to 46.99 per cent sodium chloride, making a total of 60.44 and 51.55 per cent of the sulphates. Sodium sulphate was the only sulphate used in Mr. Hart's tests, which serve to indicate the relative injury due to the different forms of sodium, and in no wise fix the concentration at which cement would be destroyed when used under natural conditions. It is known that plants will tolerate larger quantities of alkali both of the total and the several ingredients as found in nature than they will in laboratory tests and it is quite probable that the same is true of cement. In the case of plants it is known that the different alaklies have a neutralizing tendency in their toxic and corrosive effects when together and experience with cement in alkaline soils and water as against laboratory tests seems to point to like results.

If clay tile can be readily had at satisfactory prices it should be used for drainage of alkaline lands. Where the salt content is low and only an excess water is to be removed, the cement tile is just as good.

There are localities where neither clay nor cement tile are procurable and where lumber is comparatively cheap. In such cases drains made of wooden boxes are specified and have given satisfaction. Lumber will last indefinitely when completely saturated and submerged, wooden water pipe from 50 to 300 years old having been removed from the ground in a good state of preservation. The uses and conditions are not exactly the same as in drainage, but they point to relatively long life. The destructive agencies work most rapidly with alternate wetting and drying, and while the drain box is exposed to air currents it seldom becomes dried out while in the ground. From observations covering 5 years it seems that alkali has no damaging effects on the wood. The nails will be practically destroyed within a few years, but ordinary small drains hold their form without nails after that time. Large drains of this material should be so designed as to prevent collapsing when the nails rust away. A form of small box drain is shown in Fig. 6, larger boxes being made as the necessaries demand. If the ground is firm and stands well without caving they may be made by using long side boards or plank as in the ordinary road culverts. If there is a tendency to cave, so that only a few feet of trench can be left open at a time, they may be put together in sections just the width of the lumber used, like boxes without top or bottom. When joining successive sections, they should be set so as to lap far enough to nail. This will hold them in position while backfilling, and subsequently from vertical displacement. Very unstable soil conditions may require an open ditch with sloping sides, and channel made of boxes. If filled around with sand and gravel these may be covered and backfilled. The chief need of an open ditch is that of avoiding expensive shoring. If large ditches must be made through soils of this character, such as are found in eastern Utah and western Colorado, this method should be used. Tile could also be laid in such formations with these precautions. Regular construction methods are given under the title Construction Methods.

Carrying Capacities.

As a basis for determining the capacity for drains, the amount to be provided for must be determined. Sugges-

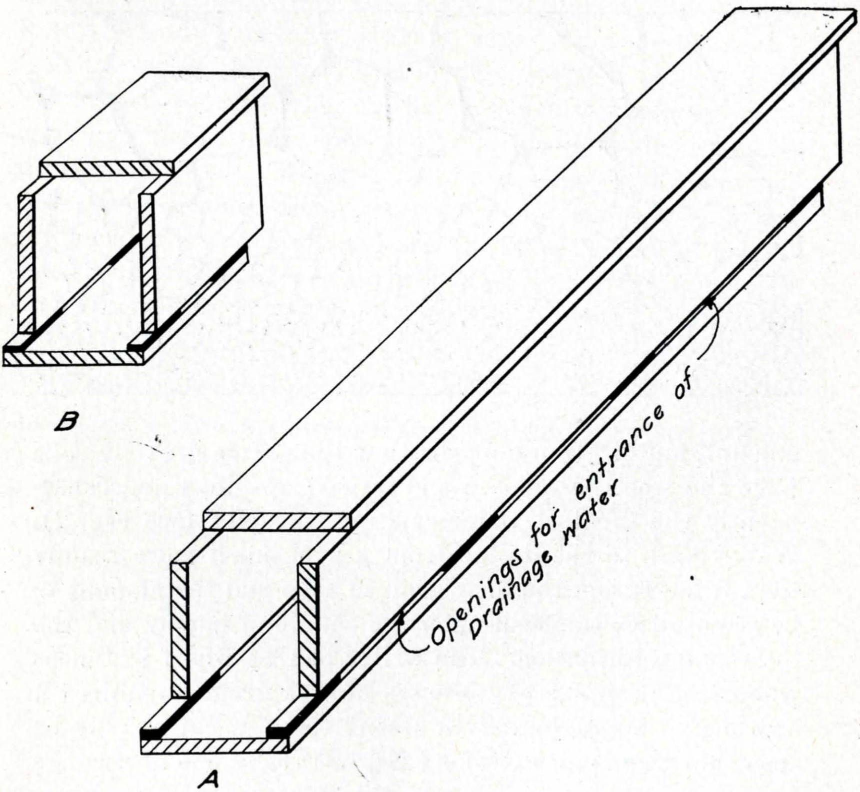


FIG. 6

LUMBER BOX DRAIN
A For use in Firm Soils
B For use in Caving Soils

tions for securing data along these lines were made in discussing the advantages of water fluctuation observations and soil prospecting. The total pore space in soils ranges from 15 to 20 per cent for certain gravels and sand to 70 per cent for fine clay. Most cultivated soils have a pore space ranging from 35 to 50 per cent. The soils having the greatest pore space do not of necessity require drains of the greatest capacity, the movement of ground water being more dependent upon the size of the spaces than upon the

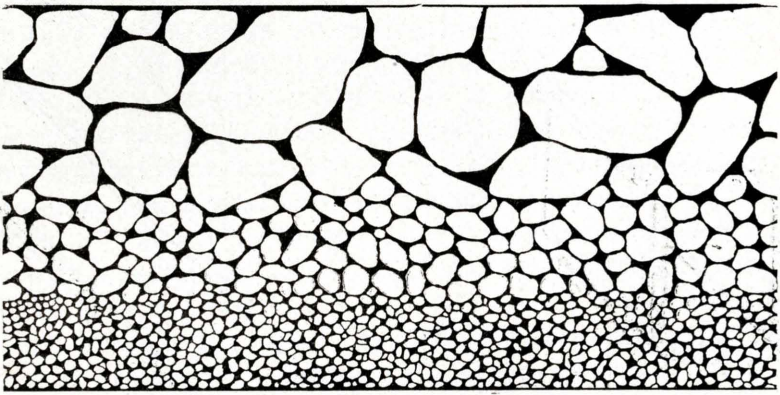


Fig. 7——Relative Porosity and Water Carrying Capacity.

amount, and it often happens that the coarse gravelly soils have the least pore space and largest openings and consequently the greatest water carrying capacity (see Fig. 7). Water flows to the drains from gravel much more readily than it does from the finer grained soils and the amount to be removed will depend upon the source of supply and the intervening formation. The writer has known of instances where the drainage of 10 acres of wet ground required a capacity of approximately 2 second feet. It can readily be seen that this is an extreme case, but really one of seepage from a definite source, as in this instance such seepage would mean surface streams which could be measured. In general, gravelly soils will require a capacity of one cubic foot per second for each 80 to 100 acres, and these indicate the collected seepage of higher lands or direct losses from canals and natural channels. Sandy soils when wet from considerable acreas of higher land will require a second foot capacity for each 100 to 250 acres and loam soils a second foot for each 150 to 300 acres, depending upon the sources of saturation and clay present.

These figures may be used in determining the sizes of main tile drains and outlets for farm of from 80 to 320 acres. Minimum sizes of less than 4 inches in diameter are not advisable under any circumstances, and not less than 6 inches in diameter for gravelly soils. In clay loams, 4-inch tile up to 2000 feet long with a grade of .1 foot per 100 feet is permissable. In fixing the intermediate sizes good judgment and an idea of the relative carrying capacities are required. The area and approximately the carrying capacities vary directly as the square of the diameter of the tile; that is a 10-inch tile has four times as much capacity as a 5-inch tile on the same slope, the carrying capacity in any case being directly dependent on the grade or fall in the line.

It is not the purpose of the author to furnish complete instructions from the standpoint of the engineer, but rather the basic principles to be adopted by engineers for all work and by farmers for small jobs such as they feel inclined to undertake. It is the intention to enable the farmer to drain his land with the minimum outside aid.

Large districts where the total water to be removed comes from the seepage of irrigation water, and not from other sources, require an outlet capacity in second feet of one-third the amount in second feet distributed during irrigation. Or, in other words, the amount discharged through the main drains will equal one-third of the total applied in irrigation. The actual duty of water in the irrigated sections averages one second foot for each 60 to 80 acres, or 3 to 4 acre feet of water per acre in four months. The discharge capacity for whole irrigation districts should then be one second foot for each 180 to 240 acres. It rarely happens that all the land irrigated by a canal in one natural drainage division and from which seepage comes, is incorporated within one system of outlets, so that the per acre discharge should be increased accordingly. Laterals serving sub-divisions liable to unevenness in distribution and seepage are provided with a capacity of one-half the amount applied. These discharge capacities for large districts came from the English practice in Egypt and India and have been observed to hold for western arid regions.

To the engineer and practical irrigation farmer, it would not be necessary to mention the principle that the size of the channel must be governed by the amount of water to be removed. Evidently, then, mains and sub-mains must be larger, that is, have more discharge area below the allowable depth of surface flow than is necessary in laterals and single lines. The trunk lines of drainage must carry the combined discharges of all laterals.

One of the chief controlling factors of the discharge capacity of any water channel is its roughness. Any roughness on the sides and bottom of a drain tends to prevent flow and will materially diminish the flow, or back the water up until sufficient head is created to cause the necessary movement. When the water backs up to a greater degree than the grade or slope of drain allows, the result is the raising of the ground water table, preventing real drainage to that extent. Hence the need of using smooth tile and securing even joints will be apparent to all. The difference between a lumber box drain surfaced and unsurfaced on the inside is very marked in favor of the surfaced lining. The chief cause of the inefficiency of open drains is the roughening caused by weeds, small clods and bank soils slipping down and obstructing the flow.

The subject of grades or slopes given to the drain is one that demands close attention. Enough slope must be given or allowed to move the water away as fast as gathered. The inherent tendency of water to create sufficient head, even to the extent of submerging the pipe lines, is depended on for the very maximum amount to be discharged. When the period of greatest amount of water reaching the drains passes, the head thus created recedes until the grade of the tile or drain is reached. This grade and the size of tile must be correlated so as to carry the average flow. In practice the least grades for tile are .1 foot per 100 feet, or .1 per cent grade. Extreme cases may necessitate laying tile on a grade of one-half this amount, but such reduction should only be resorted to after careful computations as to sizes required and the cost of making a deeper outlet.

Root Troubles.

The location of tile lines with proper reference to growing trees and plants liable to develop troublesome water roots, is a question that must not be overlooked. This tendency is more marked for all trees in the arid than in the humid regions, on account of comparative drouth during some seasons and the inclination of the roots to seek water. Cottonwood trees have been known to send their roots more than 100 feet and cause trouble. A lumber box drain made solid to prevent the entrance of these roots was penetrated and entirely obstructed. There is some question as to fruit tree roots entering tile, but no such cases have been observed within four years of laying tile.

The writer has known alfalfa roots to obstruct a 6-inch tile when 5 feet deep, but plowing the alfalfa killed the roots and they floated out. Alfalfa three years old had not entered the tile at all, so the time when it would become troublesome would be somewhere between three and six years. In the sugar beet sections three or four years in alfalfa is enough for fertilization, and root troubles do not become serious within that time.

Beet roots gave some trouble in the Hyde Park section, stopping up a 10-inch tile and one year delaying harvesting, but a judicious use of irrigation water on these tracts prevented the injury. As with alfalfa roots, the fine water roots die and float out after the beets are dug.

In no case should tile be laid within 150 feet of water-loving plants like the cottonwood and willow. Cementing sewer pipe between trees, unless very carefully done, and extended 150 feet above and below the trees will not be effective. A large tile will be filled from a single rootlet no larger than a pencil point. More caution must be used in this matter in the irrigated regions than elsewhere.

Cost Estimates and Profitable Returns.

The cost of reclamation by drainage may conveniently be divided or discussed under four heads, namely, Engineering and Organization, Materials, Labor and Interest. Safe estimates for any and all projects may be made from this outline if all the items included are taken into account and judiciously handled. There will be a vast difference between these several items, depending upon the size of the project or tract reclaimed and the methods employed; but these elements will enter into the cost of every such scheme, and cost estimates ignoring any of them will be deficient and faulty, or reliable estimates can not be made without careful consideration of every element of charge against the proposed work. Estimates based on actual costs under similar wage and natural conditions are most dependable and should be sought for. Men are much the same in different localities, and what is accomplished on the average by one set may be expected of another set or crew under similar conditions. When a piece of work is finished a memorandum of the cost, together with a description of the material and attendant circumstances, should be made for future use.

Engineering and Organization come first on the list, and some surveys must be made before other estimates are possible, except in a very general and approximate manner. All reclamation work involving more than a few acres in extent should be preceded by such surveys as will determine the location of lines, depths of excavation and sizes of tile or waterways. Preliminary farm drainage surveys for farms of 160 acres and above will cost approximately 25 cents per acre and final staking and inspection an additional 25 cents, making the total for engineering 50 cents per acre, or about 5 per cent of the cost of drainage. These figures are based on personal experience. Engineering for districts involving tracts from 2000 acres up to 20,000 acres will cost from 5 per cent to 7 per cent of the total expenditure or approximately 30 cents per acre. These charges cover all field work, preparation of plans, estimates and specifications, together with general supervision and inspection of contract work for the large jobs. Small farm jobs are not usually inspected by the engineer, but by the owner or farmer.

Organization costs are only assessed against co-operative undertakings or state drainage districts. The items usually included are those for legal assistance and fees or court procedure incident to effecting such organizations. Under most state laws these are comparatively nominal. They may require the services of an assessment board for fixing damages and benefits to be paid in advance of organization. The State of Utah is without a drainage law just at present, so that this item cannot be fixed very definitely. It is hardly probable that this charge will exceed 5 per cent of the total cost of reclamation.

The materials necessary for farm drainage will be covered drains, either clay tile, cement tile or lumber. Western prices are higher as a rule than eastern prices, probably due to a large extent to the relative demand for such products.

The following prices f. o. b. cars for clay tile are quoted by a Utah firm:

Sizes.	Weight per Foot.	Price per Foot.
4-inch	7 lbs.	$.04
5-inch	10 lbs.	.05
6-inch	12 lbs.	.06½
8-inch	19 lbs.	.12
10-inch	27 lbs.	.20
12-inch	38 lbs.	.25
18-inch	70 lbs.	.50

Some prices on clay tile at Spokane, Washington, are given below:

Sizes.	Price per Foot.
6-inch	$.10
8-inch	.12
10-inch	.15

The following are St. Louis prices in 1909:

Sizes.	Price per Foot.
4-inch	$.019
6-inch	.034
8-inch	.071
10-inch	.10
12-inch	.13

Average prices for hard burned vitrified clay tile in Iowa during 1911 were as follows:

Sizes.	Price per Foot.
4-inch soft	$.015
5-inch "	.02
6-inch "	.03
7-inch "	.04
8-inch hard burned	.065
10-inch " "	.10
12-inch " "	.13
14-inch " "	.20
15-inch " "	.24

18-inch hard burned			.38
20-inch	"	"	.50
22-inch	"	"	.575
24-inch	"	"	.675
26-inch	"	"	.90
28-inch	"	"	1.15
30-inch	"	"	1.35

Most clay tile in the western states is made by sewer pipe manufacturers only. A more general demand will undoubtedly result in a lowering of the prices in the irrigated regions.

The cement tile for the Richfield experiment was made under adverse circumstances. Cement cost $5.00 per bbl. and a new crew had to be instructed for the work. The 10-inch tile cost $.16 1-3 per foot. The proportions were one of cement to five of sand and gravel, which is hardly enough cement to make the handling safe. Four men were used, one mixing, two tamping into hand molds and one sprinkling, etc. Labor for this job cost $2.00 per diem for 8 hours.

One man can make 20 sections per day of 12-inch cement tile in two-foot lengths, mixing his own mortar, etc. A shed should be provided for shading the green pipe and to enable work to proceed in stormy weather. The labor cost of making such tile with wages at $2.50 per day will be approximately 6 cents per foot with material on the ground. These tile should be placed on wooden pallets for about 48 hours and then stacked up.

Freight is an item that must be added to the cost of tile for most points in these parts. Close estimates will require quotations for the railroad companies as rates vary some, though a rate of 3 cents per ton per mile may be used for the intermountain region for general estimates.

The cost of unloading the tile from the cars and distributing in the field will vary from $.30 to $.70 per ton mile, depending upon equipment, amount and distance to be hauled. The greater part of this charge is for loading and unloading, so that a haul of a mile or two is not materially different from hauling only a half a mile.

The average number of feet of tile per acre of ground drained may be used as a basis of estimating the cost per acre in a general way. The following costs are taken from the co-operative experiments.

Name of Experiment.		No. Feet per Acre.	Total Cost per Foot.
Hyde Park	31.5 acres	95	$.16
Garland	60 "	105	.16
Point Lookout	40 "	133	.10
Roy	40 "	117	.12
Richfield	80 "	98	.14
St. George, solid lumber box drains, 4-in.x6-in. inside, 1320 feet outlet drain			.23

Average for tile, 110 feet per acre, $.13½ cost per foot.

The labor costs of most importance in making estimates are those of trenching and excavation, though for tile work the items of laying tile and backfilling should not be overlooked. Trenching by hand to depths of 5 feet will cost from $.50 to $1.00 per rod or from $.03 to $.06 per linear foot, depending upon the character of soil and wages. Trenching by machinery costs less for all classes of work than by hand. In Bear River Valley, Box Elder County, Utah, the contract price for machine trenching has ranged from $.60 to $.75 per rod, depending on the depth.

Tile laying and backfilling will cost from $.01 to $.02 per linear foot, depending upon the size of tile and difficulties in grading. If the ground is so soft as to require a foundation under the tile the cost of lumber for this purpose must be added. Boards 1-in.x6-in. are best for this purpose and will furnish plenty of bearing surface if continuous joints are made.

Excavation for open ditch work in ordinary soils such as usually found in land requiring drainage, will cost from 10 to 15 cents per cubic yard.

Interest on the amount invested for the period of reclamation must be charged to such projects. The time required for putting the lands into productive condition will vary from one to three years, depending upon the amount of alkaline salt to be removed and the mechanical condition of the soil. In addition to interest, the cost of cultivating and irrigating during the period required for reclamation should be added. It is estimated that three years will be required to effectively reclaim naturally alkaline lands where they have never been brought under cultivation. If comparatively free from alkali in the surface foot and in such condition that cereal crops and alfalfa can be grown from the start, interest charges should not be made if put under cultivation at once, as the returns from such crops would be profitable.

Profitableness.

As a business investment to the owner, the drainage of the once productive, but now abandoned fields in almost every irrigation region, cannot be excelled. The returns, in increased production and selling value on the amount invested, have averaged from 200 to 300 per cent. The 40-acre tract at Tremonton, on which a demonstration was made, would not yield enough to pay for cropping before 1907, and would not have realized $25.00 per acre on the market. The first year after drainage it yielded 45 bushels of oats per acre. In 1910, fifteen acres of alfalfa seed yielded $33.33 per acre, the hay yield that year being 5 tons per acre for 34 acres, and in December, 1911, the tract sold for $125.00 per acre. The cost of drainage was $13.52 per acre, and deducting the original value of $25.00 per acre, together with 10 per cent interest for 4 years, the investment has returned 700 per cent. The cut shown on below is of a young apple orchard on reclaimed land one-quarter of a mile from this experiment.

The Garland experimental tract was not worth $75.00 per acre just previous to drainage and the expenditure of $16.85 per acre enhanced the value $75.00 within one year. The area drained produced nothing the year previous to drainage, and full crops since, with a yield of 18 to 20 tons of sugar beets per acre in 1911.

The Hyde Park lands having only a nominal pasture value were drained at a cost of $15.60 per acre and have produced abundantly ever since. They are planted to sugar

beets largely and the average yield last year was over 20 tons per acre, with 35¼ tons per acre on 1½ acres of the reclaimed land owned by S. E. Lamb. The cut shown in Fig. 9 is from a photograph taken last October showing beet harvesting on these lands. This land is now valued at $300.00 by the owners.

A bad tract of alkali land at Roy, near Ogden, was drained at a cost of $13.67 per acre, enhancing its value several times. Choice strawberries, tomatoes and potatoes are now being grown where nothing of value would grow before. A system of drainage for the Richfield area of 80 acres, costing $14.02 per acre, has made the land worth double what it was before and it is getting better every year.

Construction Methods.

Except for very small areas more or less elaborate surveys are always necessary for the proper laying out of drainage systems. The extent and nature of these surveys will be dependent on the size of the area, the topography and surface slopes. The extent of subsurface examinations or surveys for determining governing factors, i. e. hidden hardpan dykes, sand strata, etc., cannot be determined beforehand, and is largely a matter of proper judgment on the part of the engineer in charge of the work.

For small areas, 40 to 160 acres, and where the surface slopes are such that a general plan of drainage can be determined by an inspection of the premises, it will perhaps be sufficient to run several "level lines," following the various proposed or possible routes for the drains.

A "level line" being a survey to determine the relative surface elevations along a given line, from which the slope of the ground surface is determined, and the grade or slope of the drain, also the quantity of earth to be excavated. Such a survey might be successfully made without the services of an engineer; a surveyor or anyone familiar with the use of the level instrument being capable of making this kind of survey.

In most instances, however, conditions will be found to be such that it will prove to be an economy to engage the services of a competent engineer to make the surveys for determining the location and grade of drainage channels, whether open ditches or tile drains. At some time, prior to completing the excavation of a trench or ditch, it is always advisable and usually an absolute necessity to set a line of stakes along the edge of the excavation, from which to determine the exact depths of cut for bringing the bottom of the excavation to a proper and uniform grade. These stakes should be set not more than 100 feet apart.

Trenching is usually laid out by pairs of stakes, one a guide stake on which the station and the depth to dig are written and the other a hub driven to the surface of the ground from which levels are taken and these measurements made. The best method of grading the trenches uniformly between these stakes is shown in Fig. 10. A standard or measuring stick with a perpendicular arm adjustable at a convenient length, usually 6 feet, is provided, and stakes driven so that their tops are so much above the hubs as the difference between the depth of trench cut to grade and the length of the stick. A wire is stretched across the tops of the sticks when driven to place, which is then parallel to the grade and just 6 feet above bottom of trench at every point, so that the excavation will be at grade when the cross arm just touches the line, as in the illustration.

For large areas, ranging into "drainage districts" the problem of properly locating the drains and outlets often becomes a very complicated one, requiring a considerable amount of study. In such cases it will usually be found impracticable to rely on a series of "level lines" to furnish sufficient and properly related information upon which to base a plan or layout of drains. In such cases a "Topographic Survey" is highly desirable and necessary. The object of a topographic survey is to obtain the relative elevations of the surface of the ground over the entire district and all other features of value in laying out a system, with the proper distances and directions. From this information a map is made showing at a glance the various directions and amounts of slopes, etc. This is usually done in the form of a "contour" map, on which points of equal elevation are joined by continuous lines, called "contour lines." A typical contour may is shown in Fig. 11. Such a map properly made and interpreted forms the working basis for laying out any desired system of drains, which being de-

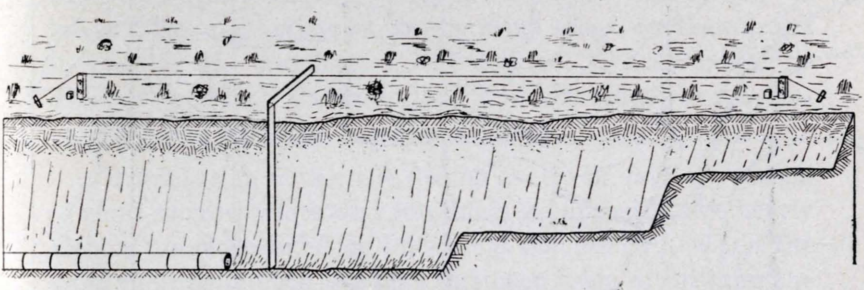


FIG. 10

termined on, are transferred to the ground for use in construction by the use of the transit or leveling instruments. There are several methods of making Topographic Surveys, each being adapted to special conditions. These are of little interest except to the surveyor and engineer, and will not be discussed here.

It is obvious that the larger the job the greater must be the care in making surveys. Small errors in a single line might be of no practical consequence, while a number of small errors in a large job might combine to make a large one and lead to serious confusion or trouble. Also where there are several possible routes for drains, especially with reference to open ditch outlets, an accurate estimate must be made of the excavation required for the various routes, which, together with the nature of the material, will determine the most economical route.

Topographic surveys for large areas will cost from $30 to $60 per square mile, or $.05 to $.10 per acre, for average open country. Where trees and brush are very thick, this will be more. Such surveys would make possible preliminary locations and estimates of the cost of reclamation necessary for reporting on proposed projects.

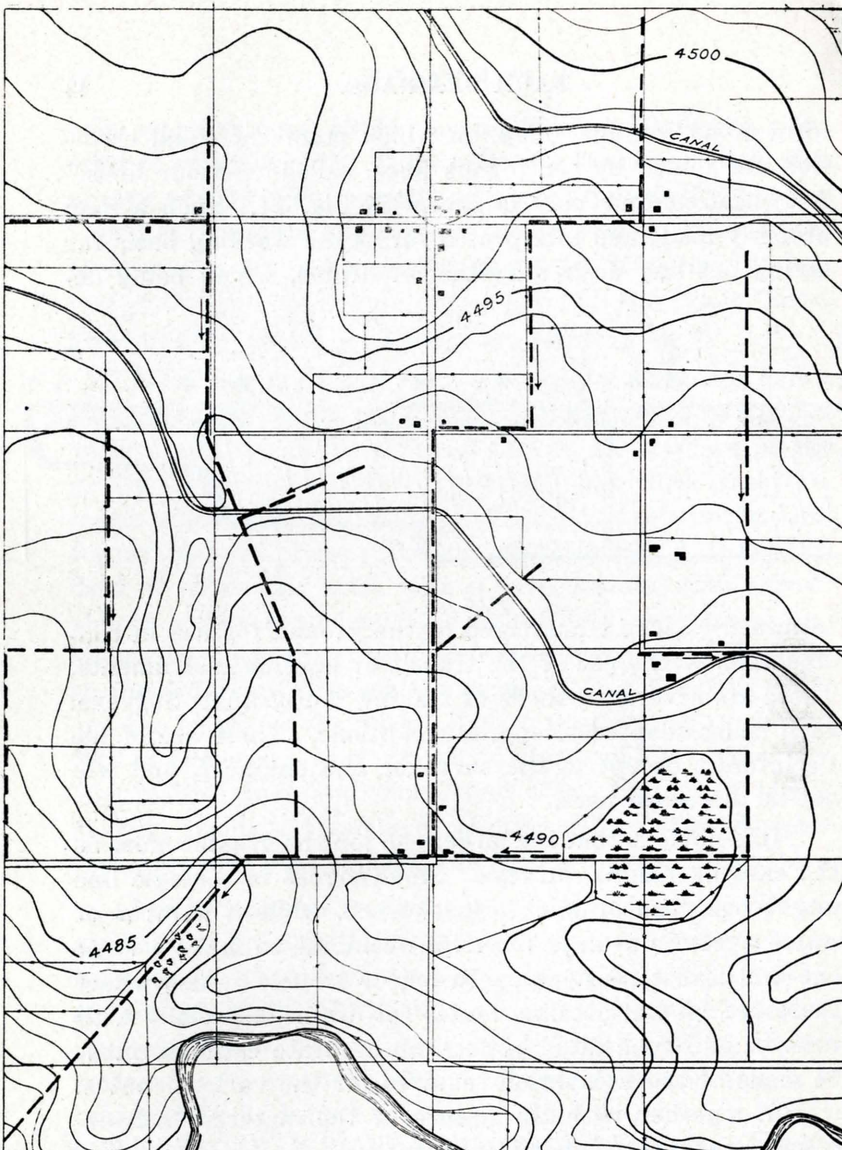


FIG. 11

TOPOGRARHIC MAP

PART OF PROPOSED DRAINAGE DISTRICT

Scale

0 1/4 1/2

Miles

CONTOUR INTERVAL 1 FOOT

Legend

Fence Lines

Roads

Swamp

Canal

Proposed Drains

River

Contour Lines

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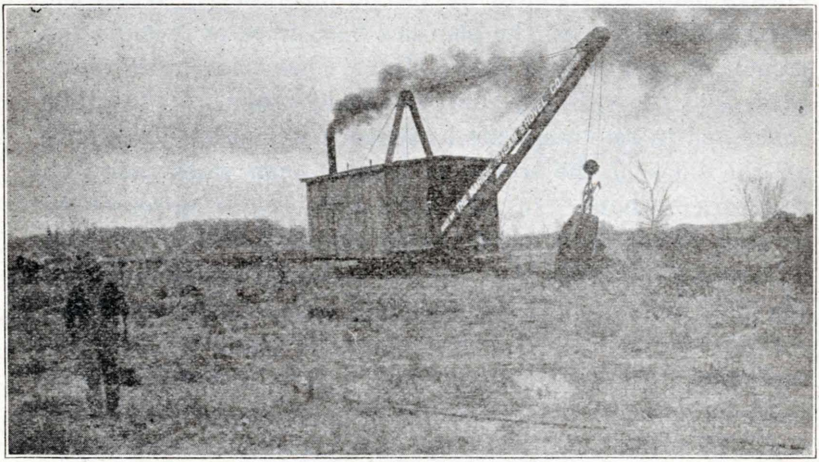
Excavation of Ditches.

There are several methods of excavating ditches and drains, dependent largely upon the size and nature of the excavation, character or material, cost and availability of labor. The most common are by hand labor, by teams, and by machinery. Excavation by water or "Hydraulicking" is possible in special instances and a new method, by the use of dynamite, has been recently developed.

Trenches in which tile drains are to be laid, by reason of their narrow width and relatively great depth, are nearly always made by hand or by special machinery. When the hand method is used the plan has been tried of opening the trench by means of a plow. Experience has shown, however, that for ordinary soils, especially when wet, the time consumed in removing the loosened material and trimming off the sides of the trench is greater than when doing all the work by hand. In very hard soils, requiring loosening by pick, it has been found that a plow can be used to good advantage to depths of 4 feet for loosening the soil, setting the plow handles close together and using a horse on either side of the trench. A special form of spade is made for trenching, called a ditching spade. It is customary, especially in very wet soils, to excavate to only a part of the full depth at a time, removing the last portion, the full depth of the spade and down to grade just before laying the drain tile or box. This does away with much trouble from caving and water, which is usually found at or near the bottom of the trench.

The scarcity of labor, and the disinclination of many laboring men for this class of work has resulted in the development and the use quite generally of trenching machines, the results obtained having been highly satisfactory. These machines have an average daily capacity of 1000 linear feet of finished trench per day and the cost is much cheaper than when done by hand. The revolving cutting wheel type, mounted on a wide base, shown in frontispiece, has given the best satisfaction. These are made in several sizes. The smaller size, with a maximum depth capacity of 5½ feet and 15 inches wide is not very well adapted to trenching in this region, where practically all trenches are cut to the full depth, thus requiring its operation to full capacity nearly all the time. The cost of operation of the next larger machine, having a capacity 7½ feet deep, is not much greater than the smaller one, and it is adjustable for cutting to any depth less than its maximum. These machines cut easily through formations which when exca-



vated by hand require loosening by pick, but they do not work successfully in bowlder formation. In soft or water bearing earth it is necessary to lay the tile as soon as possible after the machine, on account of caving.

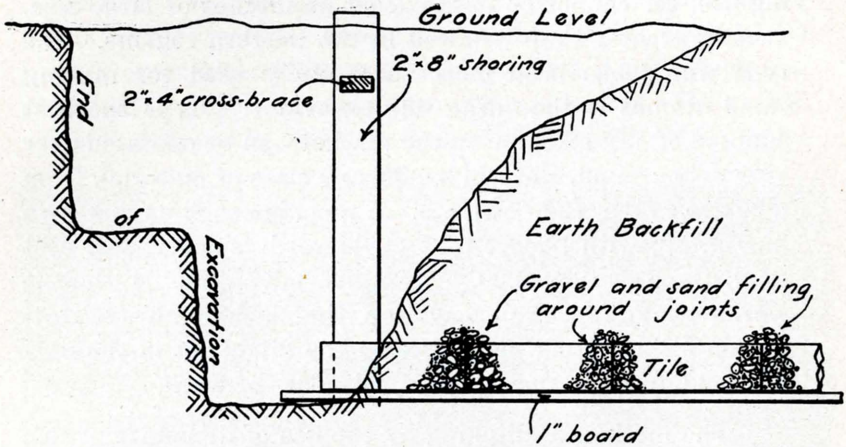
Open ditches, if large enough and sufficiently dry to allow team work, are more economically excavated by team than when done by hand, though some hand work may be necessary in trimming up the slopes. Such ditches are usually made with a 1 to 1 slope on one side and 1½ or 2 to 1 on the other, and the waste placed on the flatter slope side to enable the teams to get out of the ditch easier. It is sometimes possible to excavate in wet material by using slip scrapers and chains, keeping the horses on top, but a hard surface must be had, and even then trouble from slipping can hardly be overcome.

When much water is present it becomes impossible to use teams and a machine dredge must be resorted to. Floating dredges cannot be used except on ditches of large size, usually greater than required in the western regions. The type which has been most successfully used for making small ditches is the "drag line excavator." It is the best adapted of any machine on the market, can be operated over very soft ground, and will handle any class of material, from muck to gravel and bowlders. A machine such as is shown in Fig. 12, with bucket of 1 cubic yard capacity, will cost approximately $5000.00. Its chief advantage is that it works away from the excavation, the machine always resting on solid ground instead of in the ditch. It is the only dry land machine successful in this class of work.

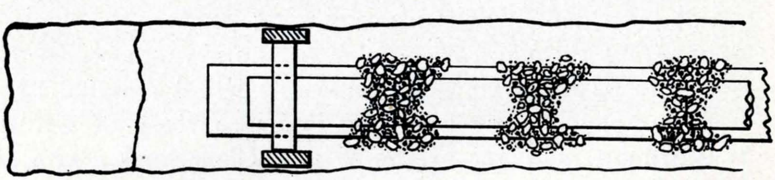
The method of ditching by the use of dynamite, which has been evolved of late, has been used with success in making small open ditches, but its value for large ditches has not been demonstrated as yet. Its success is dependent upon the thorough saturation of the lower portions of the soil to be removed, and seems to be best adapted to open porous soils. The following is by courtesy of Dr. H. C. Gardiner, manager of the Willow Glen Stock Farm, Anaconda, Montana.

A row of holes about 3 feet apart made with soil auger or crow bar, is put down to the full depth of the ditch along the center line. The amount of dynamite to be used varies with the character of soil and depth and is best determined by trial. Two or three charges in a section 300 feet long are fired electrically by means of a magneto and the remainder are set off by the detonation. All the charges explode at the same time and the waste material from the excavation is scattered to a distance of 50 feet. A comparatively smooth ditch 3 feet wide on bottom, 5 feet deep and 10 to 12 feet wide on top, 1320 feet long, was excavated by this method in eleven hours by four men, using $40 worth of dynamite, or a total of 2.9 cents per cubic yard.

Further cost data relative to trenching and ditching will be found under "Cost Data."



SIDE SECTION ELEVATION



PLAN

FIG. 13

Showing method of protecting tile against filling by sand and silt, and of shoring trench in soft ground to prevent caving

In trenching the question of shoring or bracing to prevent caving often comes up. As a rule, the cost of bracing as commonly used in sewer trenches is prohibitive for farm drainage. When shoring is necessary, the best plan is that of opening the trench in short sections 6 to 8 feet head of the tile, laying the tile as close as possible to the heading and using one set or at most several sets of braces at the end of the excavation, as shown in Fig. 13, which will usually prevent caving. Backfilling must follow the laying of tile as closely as possible. Probably the only condition under which an elaborate set of shoring can be economically used is in very loose gravelly soils, which will not stand up even at moderate depths, and where a single line of

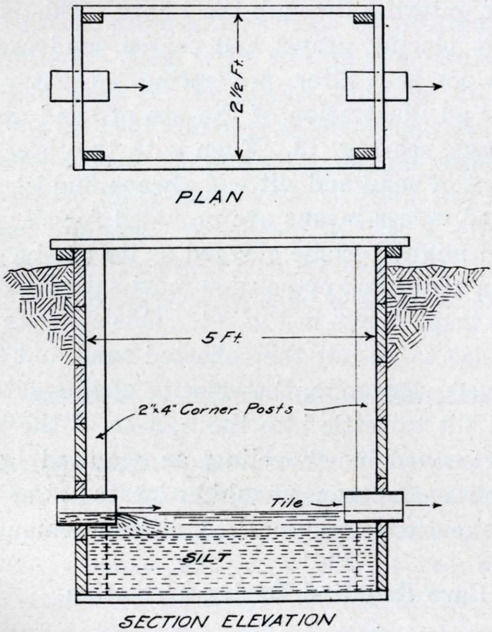


FIG. 14

tile will serve to drain a large area. In laying tile or box drains in trench, sufficient precaution must be taken to insure their being laid on a uniform grade and straight, with joints properly made. In firm soils, where the trench will stand without caving and the bottom can be accurately trimmed to grade, this is a comparatively simple matter, and the only further care necessary is in backfilling, to see that the sections of drain are not moved out of line. In soft or caving soils where it becomes necessary to work rapidly and where it is not possible to accurately grade the bottom of the trench, or where there is danger of the tile being forced out of grade, the simplest and best expedient is to place a 1-in.x4-in., or 1-in.x6-in. board in the bottom of the trench on which to lay the tile. Sufficient backfill should be well tamped around the tile to hold it securely in line.

Where fine sand or "running" or "creeping" silty soils are present, it is necessary to protect the drains from being filled by these entering through the joints. This is best accomplished by placing gravel and coarse sand around the joints, which act as a filter, preventing the entry of sand and silt. For an illustration of the use of sand and gravel for this purpose, see Fig. 13. Even with this precaution, a certain amount of sand and silt will always find its way into the drains, and unless means are provided for cleaning this out, the drain might become clogged or its use be seriously impaired. An additional precaution most satisfactory is the use of a sand trap, shown in Fig. 14. This consists of a box of sufficient size to permit the collected sand and silt to be readily removed. Reducing the velocity of the water allows the sand and silt to settle into the bottom of the box from which it is removed by shoveling, as required to prevent clogging. These sand traps should be located at as frequent intervals as experience and local conditions demand.

Care Required During Irrigation.

Irrigation water constitutes a menace to the efficiency of covered drains, especially when laid in fine said and silt. The water readily finds its way through the loosely filled trenches and carries its load of silt and sand into the tile, frequently causing obstructions that require the removal of the tile to remedy. The best preventative for this trouble in loose formations is to place sand and fine gravel around the tile before backfilling. Some such treatment is absolutely necessary for tile or boxes in soil consisting mostly of silt and fine sand. It may be advisable also to back furrow over tile lines and convey the water supply across the same in flumes or boxes. Even where sand and gravel are used as packing, these precautions should be taken in the silt soils of the eastern part of Utah and throughout the Colorado Plateau.

Sand traps as shown in Fig. 14 should also be put in at convenient points to guard against such obstructions. With these traps and frequent flushing by irrigation water during construction, obstructions may be prevented in quicksand formations. Such wells will fill comparatively quickly during active work on the drains, but the sand will finally cease flowing so that cleaning is not required oftener than once or twice a year. Lumber box drains open on the bottom are sure to fill in such soils, so their use without bottoms is bad practice. As shown in Fig. 6, small openings should be left on the lower corners to admit the water, and these should be covered with sand and gravel except in clay or gravelly soils.

Removal of Alkali and Reclamation.

Lands just beginning to fail from too much alkali, and those having only an excess of water, are the only ones where complete reclamation is effected as soon as drainage is provided. Copious irrigation will be required to carry away the excess of salts and should be accompanied by cropping and cultivation. Where there is a good covering of grass, heavy irrigation for one season before breaking may be advisable. As a rule, though, the land should be broken and worked as much as possible for improving its mechanical condition. Breaking and the application of land plaster where there is black alkali present is the best thing that can be done for clay soils. The land plaster or ground gypsum will cause a flocculation of soil particles, loosening the puddled condition and liberating the soil humus, both caused by the action of black alkali. One of the chief advantages of cropping during the leaching period is the shade furnished by the growing crops and the reduced evaporation. Sweet or bull clover is a natural resistant to alkali, and besides furnishing abundant shade, will thrive with copious and frequent irrigation. If cut when about two feet high, this plant has a forage value making it worth while to handle. Cutting two consecutive seasons so as to prevent seeding will completely remove the stand. Oats and barley are the most resistant of the cereals and best adapted to reclamation of these lands.

With lands heavily charged with alkaline salts, irrigation water should be so distributed as to completely submerge the surface. If small ridges and knolls are left uncovered while the balance is submerged with water, accumulations of alkali will gather on the ridges and knolls, and especially along the border of saturation, to such an

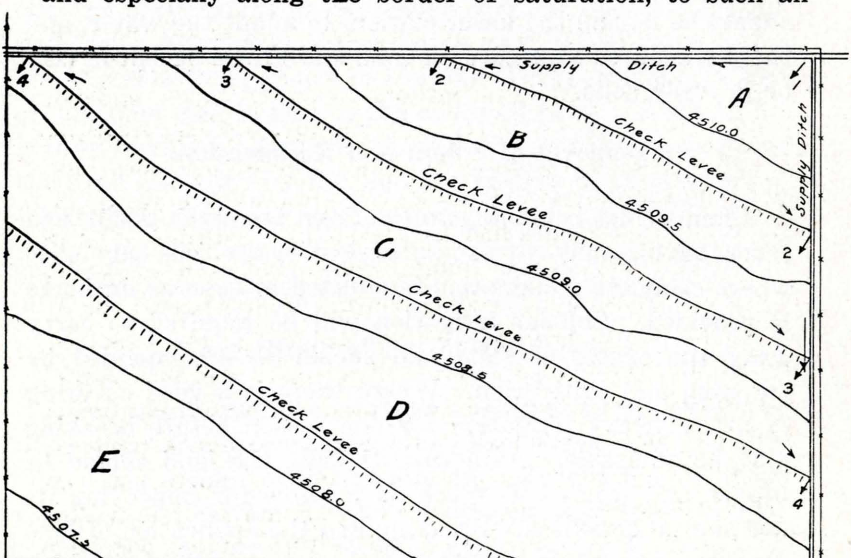


FIG 15

extent that it would seem that the alkali from the submerged portions was gathered to such places. This peculiarity must be due to the higher rate of evaporation from the wet but uncovered soils and the replacement of alkaline-charged waters by capillary soil water. The advantages of the contour check method of irrigating such lands is no doubt due to this phenomonon of evaporation. In many cases this method has failed, but mainly for the reason that the checks were laid out in rectangles without regard to the topography, making complete submergence very difficult by reason of the too great differences of elevation between the different portions of the check. The method is only practical for comparatively level land, and then the checks should parallel the lines of equal elevation and be provided with ditches for removing the ponded water. This method and the flooding method are the only practical ways of irrigating for the removal of alkali where it is concentrated at the surface. The contour check method is illustrated in Fig. 15.

Several alkaline resistant plants of agricultural value have been mentioned above and there are others tolerating relatively large amounts without being seriously affected. Old alfalfa, after becoming well established, has tolerated or resisted large amounts of alkali where the roots have not been submerged. Instances are known where an excellent stand of alfalfa has been broken for rotation of crops and the surface soil was found to be so excessively alkaline that other crops could not be grown. In such cases the alfalfa could not be re-established on account of the sensitiveness of the young alfalfa plant. The sugar beet is resistant to a limited extent and where a stand can be secured grows very rank and luxuriant, but the sugar content is rendered unavailable so that the manufacturers of sugar do not want them. Some plant naturally resistant to the alkaline soils of the west, and having agricultural value, has been sought for in vain by Government experts and others for many years.

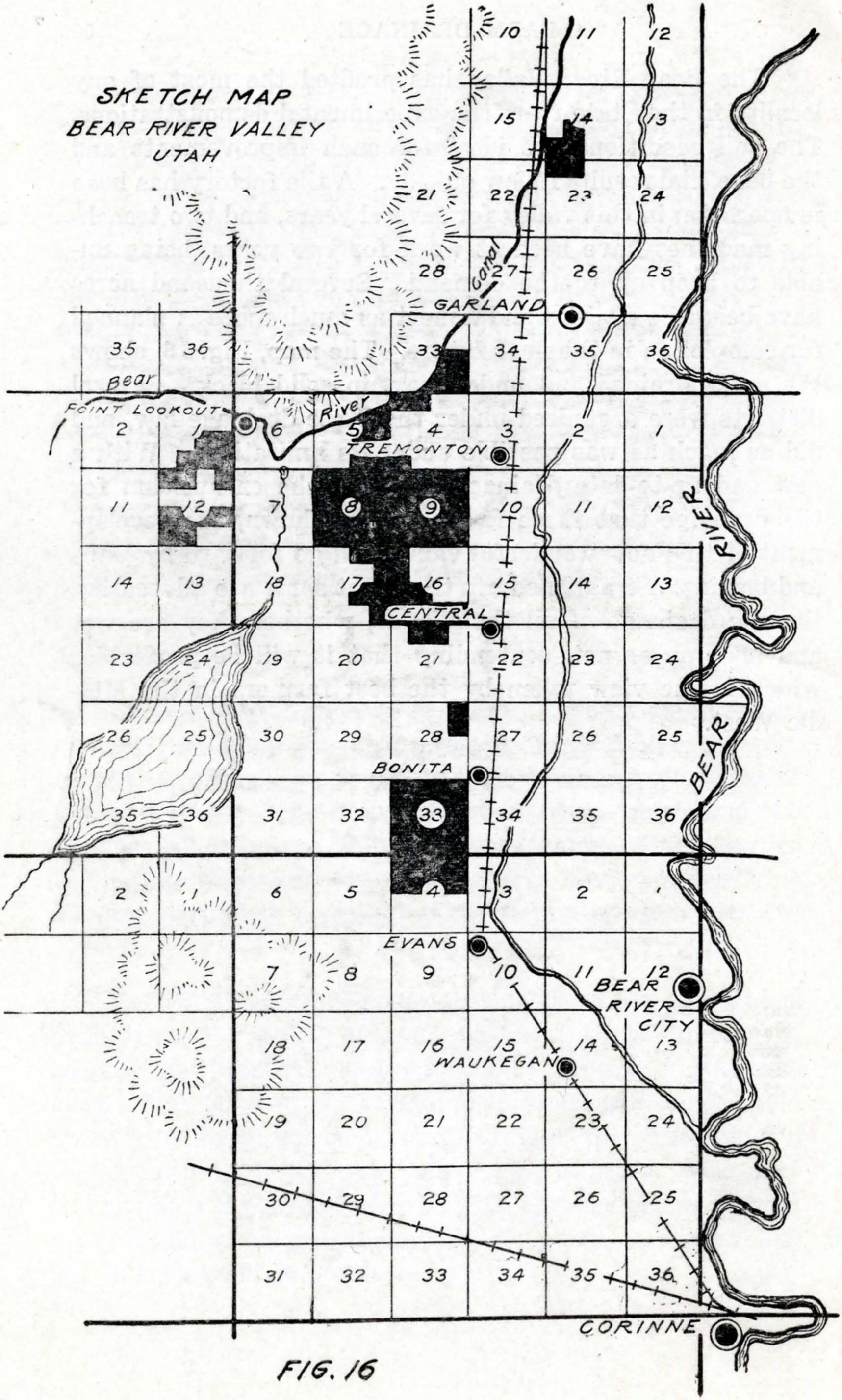
The time required for reclamation as stated before, will vary from one to five years, dependent upon natural conditions prevailing and the methods used. The lands of Cache Valley, affected only by excess of water, and some in the Bear River Valley in the earliest stages of seepage and alkali, responded with full crops the first year. Most of the other areas responded with paying crops the first year with increasing yields for from one to three years after. Virgin soils capable of producing one or two crops without drainage will improve each year with drainage and should reach the maximum production within three years if properly cultivated and fertilized.

The abundant supply of lime in most arid regions corrects any acidity as soon as the excess of water is removed, being an advantage over conditions prevailing in the humid regions, where lime must be added or considerable time of areation be allowed.

Some question has been raised concerning the permanence of improvements effected by drainage and the possibility of such lands reverting to their former states of unproductivity. The only thing that could cause such reversion would be the failure of the drains. Hard burned tile is practically indestructible and has been removed from alkaline ground in a perfect state of preservation after 20 years.

Very few irrigated lands, except those already underdrained, can be said to be perfectly free from the menace of seepage and alkaline accumulations. Ground water has risen 40 to 50 feet, waterlogging agricultural lands, and there is no doubt but that many farms in the older regions, to say nothing of the new, will yet be affected. The only thing that will prevent seepage with the rise of the ground water table is underdrainage, which, when once provided, is a guarantee of immunity.

The Bear River Valley has profited the most of any locality in the State from the experimental demonstrations. The soil conditions are ideal for such improvements and the beneficial results follow quickly. A tile factory has been in operation in this valley for several years, and two trenching machines have been at work for two years, being unable to keep up to the demand. Several thousand acres have been tile drained and almost as much more is planned for completion in the near future. The map, Fig. 16, shows the areas drained and under way, in solid black. Several districts were organized under the State drainage law, and did as much as was possible under its limitations. With a new and up-to-date drainage law, and the enthusiasm for tile drainage that these farmers have shown, the development of this now wonderful valley will go forward by leaps and bounds. So satisfied are they that some are advocating the tile drainage of all their lands, whether they are wet and alkaline or not, contending that it will be profitable; which is the view taken by the best farmers in the Middle West.



SKETCH MAP
BEAR RIVER VALLEY
UTAH
Canal
GARLAND
Bear
River
POINT LOOKOUT
TREMONTON
CENTRAL
BONITA
EVANS
WAUKEGAN
BEAR RIVER CITY
BEAR RIVER
CORINNE

FIG. 16